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REMOTE DISCRETE-TIME MODEL REFERENCE ADAPTIVE CONTROL OF A TWO-WHEELED MOBILE ROBOT

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ABSTRACT

This paper demonstrates a remote discrete model reference adaptive control for a two-wheeled mobile robot where actuators, sensors and controller are distributed and interconnected by a wireless communication. Since a typical feature of wireless communication, a piecewise constant input, discrete-time controller and model of mobile robot are adopted to analyze the stability and the performance based on Lyapunov stability theory. The proposed controller accommodates the effect of uncertainties and mismatching modeling, time delay of the control plant by discrete-type adaptation laws. A prototype of mobile robot is utilized for controlling by the computer-based proposed controller through Lora wireless communication. Some experimental results are given to verify the control performance of the proposed controller.

KEYWORDS: Discrete Time, Mobile Robot, Model Reference Adaptive Control & Remote Control

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Original Article

1 INTRODUCTION

Automated guided vehicles (AGVs) have been increasingly used for material transport in facilities such as warehouse, plant, distribution center and transshipment terminal (Le *et al*, 2004). The uses of AGVs play a key role in reducing labor cost, increasing the efficiency and reliability in storage process. Nevertheless, the major challenge is to design a controller which offers more efficient re-configurability, better resource utilization. The typical structure of traditional AGVs is a two-wheeled mobile robot equipped a locally controller (Ngo *et al*, 2007; Hossain *et al*, 2013; Ali *et al*, 2010). There are many such mobile robots used in facilities for handling material. Each mobile robot involved a maneuver controller, communicates to a control station for logistic control and collision avoidance. This type of control architecture costs significant for installation and maintenance. Modern control applications concerning mobile robots can benefit from the utility of wireless communication technology for remote control (Lozoya *et al*, 2007). Based on the benefit of the remote control, a typical architect of AGVs introduces a central controller, sending and receiving, through a wireless network, the controller commands and the sensor signal to the mobile robot, respectively. However, the typical feature of a wireless AGVs system is to generate random communication delays, which cause severe the overall control performance. Some previous research works (Lian *et al*, 2001; Walsh *et al*, 2002; Wang *et al*, 2004) carried out the analysis and control performance improvement to accommodate the negative effect of time delay in the remote control. Researchers (Halevi *et al*, 1998) studied continuous-time plant and discrete-time controller to develop a remote

control using discrete-time approach. In (Nilsson, 1998), the authors analyzed the remote control system in discrete-time domain. The research proposed a LQG controller for constant time delay model. Some existing researches (Yin *et al*, 2014; Kaya *et al*, 2003) studied controllers based-on Smith predictor for unstable process with time delay, however these types of controllers cannot overcome the effect of system parameter uncertainties.

In fact, since a complex mechanical structure, a mobile robot introduces mismatching model and uncertainties such as weight, center of mass, inertia of moment, friction which degrades the stability of the control system. Existing controllers designed based on only the kinematic of the mobile robot (Carelli*et al*, 1999; Kongezos*et al*, 2002). However, in order to achieve the control task requiring high pay-load transportation and high velocity movement, it is necessary to consider and develop a controller based on the dynamic of the mobile robot. As well, in the case of the pay-load transportation, the weight of the mobile robot can change when the pay-load is loaded. It is important to develop a controller which is capable to adapt the change of dynamic characteristic (Duong *et al*, 2018). Some research works carried out adaptive controllers to obtain this objective. (Kim *et al*, 2000) investigated a robust adaptive approach for the mobile robot based on robot kinematic; however, the adapted controller parameters are not feasible of the mobile robot. Some tracking controller developed by (Dong *et al*, 2005; Dong *et al*, 1999; Liu *et al*, 2004) were subjected to mobile robots assuming uncertainties, unknown nonlinearities and parameter variation to stabilize the dynamic of mobile robots. However, these controllers were developed in continuous-time domain, while it should be achieved in discrete-time, which is implemented easily by a clock-driven controller.

In this paper, the design of a remote discrete-time model reference adaptive controller for a two-wheeled mobile robot is developed. In order to overcome the drawback of the remote control, a discrete modeling of mobile robot involving random time delay and a piecewise constant input are used for stabilizing the control system. To mitigate the negative effect of time delay and uncertainties of the control system, a discrete-time modified model reference system is proposed to obtain an adaptive controller for the remote control system. Controller parameters are updated by the adaptation law to adjust the dynamic characteristic of the remote control system in the variation of system parameters. The effectiveness of the proposed approach is evaluated by using a prototype of mobile robot controlled through Lora wireless communication.

2 PROBLEM FORMULATION

For the convenience of the control design, the dynamic equation of a typical mobile robot as shown in Figure 1 is expressed by the following equation (Zhang *et al*, 2001).

$$M(q)\ddot{q}+F(q,\dot{q})\dot{q}+G(q)q=f(t) \tag{1}$$

Where, $M(q)\in R^{n\times n}$ is an inertia matrix, $F(q,\dot{q})\in R^{n\times 1}$ is a centripetal and Coriolis matrix, $G(q)\in R^{n\times 1}$ is a vector containing gravity term, $q\in R^{n\times 1}$ is a coordinate matrix and $f(t)\in R^{n\times 1}$ is a control input.

Let define the system of Equation (1) have some known/unknown plant dynamic, the following can be obtained:

$$\begin{aligned} M&=M_k+M_u\\ G&=G_k+G_u\\ F&=F_k+F_u \end{aligned} \tag{2}$$

where subscript *k* stands for the known part and subscript *u* stands for the unknown part.

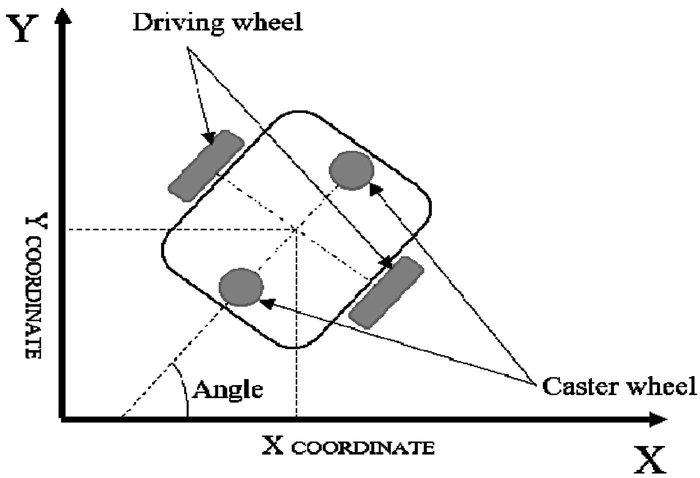

Figure 1: Two wheeled Mobile Robot in Global Coordinate

By substituting Equation (2) into Equation (1), it yields:

$$M_u\ddot{q} + F_u\dot{q} + G_u q = u \tag{3}$$

where $u = f - (M_k - I)\ddot{q} - F_k\dot{q} - G_k q$ with I is a unit matrix

Defining $x^T = \begin{bmatrix} q^T & \dot{q}^T \end{bmatrix}$ as a 4×1 state vector, Equation (3) can be rewritten:

$$\dot{x} = \begin{pmatrix} 0 & I \\ -M_u^{-1}G_u & -M_u^{-1}F_u \end{pmatrix} x + \begin{pmatrix} 0 \\ -M_u^{-1} \end{pmatrix} u$$

$$= Ax + Bu \tag{4}$$

Where, the matrices A and B are nonlinear functions of state vectors. Under considering the Equation (4), the objective to find out $f(t)$ at Equation (1) is to determine of $u(t)$.

Since the controller is implemented on a digital computer and the typical feature of the wireless network control is to generate the time delay, it is necessary to adopt a discrete-time plant of the mobile robot to develop a discrete controller. This paper assumes that the random time delay τ less than one sampling time h(*i.e.*, $\tau = \tau_{ca} + \tau_{sc} < h$) in which τ_{ca} is a controller-to-actuator delay time, τ_{sc} is a sensor-to-controller delay time.

The system described by Equation (4) can be expressed in discrete-time as follows (Dong *et al*, 2005):

$$\begin{cases} x(i+1) = \Phi x(i) + \Gamma_0(\tau)u(i) + \Gamma_1(\tau)u(i-1) \\ y(i) = Cx(i) \end{cases} \tag{5}$$

where

$$\Phi = e^{Ah}$$
$$\Gamma_0(\tau) = \int_0^{h-\tau} e^{As} B ds$$
$$\Gamma_1(\tau) = \int_{h-\tau}^{h} e^{As} B ds$$

3 CONTROLLER DESIGN

The goal of controller design is to construct a discrete control input vector $u(i)$ and adaptation parameter such that the output of the system described in Equation (5) tracks closely the output of a modified reference model.

Let the discrete time modified model reference be given as follows:

$$x_m(i+1) = \Phi_m x_m(i) + \Gamma_m^0 r(i-1) + \Gamma_m^1 r(i) \tag{6}$$

Where, $x_m(i)$ is the modified reference model state vector, $r(i)$ is a piecewise constant reference input of the system described in Equation (5) and Φ_m are a Hurwitz matrix.

The adaptive control input which stabilizes the control system described in Equation (5) is given by:

$$u(i) = -\hat{\Theta}_\alpha^{-1}(i)\left[\hat{\Theta}_x(i)x(i) + \hat{\Theta}_\gamma(i)u(i-1) - \hat{\Theta}_r^0(i)r(i-1) - \hat{\Theta}_r^1(i)r(i)\right] \tag{7}$$

Where, $\hat{\Theta}_\alpha(i) \in R^{4\times2}$, $\hat{\Theta}_x(i) \in R^{4\times4}$, $\hat{\Theta}_\gamma(i) \in R^{4\times2}$, $\hat{\Theta}_r^0(i) \in R^{4\times2}$ and $\hat{\Theta}_r^1(i) \in R^{4\times2}$ are adaptation parameter vectors.

To stabilize the close-loop control of Equation (5), a tracking error vector is defined as follows:

$$e(i) = x(i) - x_m(i)$$

$$e(i+1) = x(i+1) - x_m(i+1) \tag{8}$$

By substituting Equations (5–7) into Equation (8), it yields:

$$e(i+1) = (\Phi - \Phi_m)x(i) + \Phi_m e(i) + \Gamma_0 u(i-1) + \Gamma_1 u(i) + \Gamma_m^0 r(i-1) + \Gamma_m^1 r(i) \tag{9}$$

The goal is to have $\lim_{x\to\infty} x(i) = x_m(i)$, or in other words $\lim_{x\to\infty} e(i) = 0$, therefore, assuming that there exists a $\Theta_x \in R^{4\times4}$, $\Theta_\alpha \in R^{4\times2}$, $\Theta_\gamma \in R^{4\times2}$, $\Theta_r^0 \in R^{4\times2}$, $\Theta_r^1 \in R^{4\times2}$ and a known system parameter $\Gamma_n \in R^{4\times4}$ such that

$$\begin{aligned}
&\Phi - \Gamma_n\Theta_x = \Phi_m \quad , \quad \Gamma_m^0 = -\Gamma_n\Theta_r^0 \\
&\Gamma_0 = \Gamma_n\Theta_\gamma \quad , \quad \Gamma_m^1 = -\Gamma_n\Theta_r^1 \\
&\Gamma_1 = \Gamma_n\Theta_\alpha
\end{aligned} \tag{10}$$

Substituting Equation (10) in Equation (9) and simplifying leads to an error of the form

$$e(i+1) = \Phi_m e(i) + \Gamma_n\Theta_x x(i) + \Gamma_n\Theta_\gamma u(i-1) + \Gamma_n\Theta_\alpha u(i) + \Gamma_n\Theta_r^0 r(i-1) + \Gamma_n\Theta_r^1 r(i) \tag{11}$$

Define the estimation errors as $\tilde{\Theta}_x(i) = \Theta_x - \hat{\Theta}_x$, $\tilde{\Theta}_\gamma(i) = \Theta_\gamma - \hat{\Theta}_\gamma$, $\tilde{\Theta}_\alpha(i) = \Theta_\alpha - \hat{\Theta}_\alpha$, $\tilde{\Theta}_r^0(i) = \Theta_r^0 - \hat{\Theta}_r^0$, and $\tilde{\Theta}_r^1(i) = \Theta_r^1 - \hat{\Theta}_r^1$. Using these definitions and the adaptive controller of Equation (7), the system of Equation (11) becomes

$$\begin{aligned}
e(i+1) &= \Phi_m e(i) + \Gamma_n\tilde{\Theta}_x(i)x(i) + \Gamma_n\tilde{\Theta}_\gamma(i)u(i-1) + \Gamma_n\tilde{\Theta}_\alpha(i)u(i) + \Gamma_n\tilde{\Theta}_r^0(i)r(i-1) + \Gamma_n\tilde{\Theta}_r^1(i)r(i) \\
&= \Phi_m e(i) + \Gamma_n\left[\tilde{\Theta}_x(i)x(i) + \tilde{\Theta}_\gamma(i)u(i-1) + \tilde{\Theta}_\alpha(i)u(i) + \tilde{\Theta}_r^0(i)r(i-1) + \tilde{\Theta}_r^1(i)r(i)\right]
\end{aligned} \tag{12}$$

By defining a $\tilde{\Psi}(i-1)=\left[\tilde{\Theta}_x(i) \quad \tilde{\Theta}_\gamma(i) \quad \tilde{\Theta}_\alpha(i) \quad \tilde{\Theta}_r^0 \quad \tilde{\Theta}_r^1\right]$ and $\zeta(i-1)=\left[x(i) \quad u(i-1) \quad u(i) \quad r(i-1) \quad r(i)\right]^T$, the system of Equation (12) can simplify to the form

$$e(i+1)=\Phi_m e(i)+\Gamma_n \tilde{\Psi}(i-1)\zeta^T(i-1) \tag{13}$$

In order to proceed with the adaptation law, let define the following

$$z(i+1)=\tilde{\Psi}(i-1)z(i-1)=\tilde{\Psi}(i-1)\zeta^T(i-1) \tag{14}$$

The adaptation laws can be given by

$$\hat{\Psi}(i+1)=\hat{\Psi}(i-1)+\varepsilon_k P(i+1)\zeta(i-1)z^T(i+1) \tag{15}$$

$$P(i+1)=P(i-1)-\varepsilon_k \frac{P(i-1)\zeta(i-1)\zeta^T(i-1)P(i-1)}{1+\varepsilon_k\zeta^T(i-1)P(i-1)\zeta(i-1)} \tag{16}$$

Where, ε_k is a positive coefficient, $\hat{\Psi}(i)$ is an estimation error vector and P_k is the symmetric positive-definite coefficient matrix which has the properties (Kokotovic*et al*, 1991).

$$P^{-1}(i+1)=P^{-1}(i-1)+\varepsilon_k\zeta(i-1)\zeta^T(i-1) \tag{17}$$

$$\zeta^T(i-1)P(i+1)\zeta(i-1)=\frac{\zeta^T(i-1)P(i-1)\zeta(i-1)}{1+\varepsilon_k\zeta^T(i-1)P(i-1)\zeta(i-1)} \tag{18}$$

Proof: Consider the following CLF

$$V(i)=\tilde{\Psi}^T(i-1)P^{-1}(i-1)\tilde{\Psi}(i-1)+\tilde{\Psi}^T(i)P^{-1}(i)\tilde{\Psi}(i) \tag{19}$$

The forward differential $V(i+1)-V(i)$ can be found as

$$\Delta V(i)=V(i+1)-V(i)=\tilde{\Psi}^T(i+1)P^{-1}(i+1)\tilde{\Psi}(i+1)-\tilde{\Psi}^T(i-1)P^{-1}(i-1)\tilde{\Psi}(i-1) \tag{20}$$

By subtracting both side of Equation (15) from Ψ, it yields

$$\Psi-\hat{\Psi}(i+1)=\Psi-\hat{\Psi}(i-1)-\varepsilon_k P(i+1)\zeta(i-1)z^T(i+1) \tag{21}$$

Let define $\tilde{\Psi}(i)=\Psi-\hat{\Psi}(i)$, Equation (18) is simplified by

$$\tilde{\Psi}(i+1)=\tilde{\Psi}(i-1)-\varepsilon_k\zeta(i-1)z(i+1) \tag{22}$$

Substituting Equation (19) by Equation (17) and using Equations (21–22), it obtains

$$\begin{aligned}\Delta V(i)=&\left[\tilde{\Psi}(i-1)-\varepsilon_k P(i+1)\zeta(I-1)z^T(i+1)\right]^T P^{-1}(i+1)\left[\tilde{\Psi}(i-1)-\varepsilon_k P(i+1)\zeta(i-1)z^T(i+1)\right]\\&-\tilde{\Psi}^T(i-1)P^{-1}(i-1)\tilde{\Psi}(i-1)\end{aligned} \tag{23}$$

$$= \tilde{\Psi}^T(i-1)\left(P^{-1}(i+1)+P^{-1}(i-1)\right)\tilde{\Psi}(i-1)-2\varepsilon_k\tilde{\Psi}(i-1)\zeta^T(i-1)z^T(i+1)$$
$$+\varepsilon_k^2\zeta^T(i-1)P(i+1)\zeta(i-1)z^2(i+1)$$

By using Equation (14), Equation (17) and Equation (18), Equation (23) yields:

$$\Delta V(i)=\varepsilon_k z^2(i+1)-2\varepsilon_k z^2(i+1)+\varepsilon_k^2\zeta^T(i-1)P(i+1)\zeta(i-1)z^2(i+1) \tag{24}$$

Simplify Equation (24) using Equation (18), $\Delta V(i)$ becomes

$$\Delta V(i)=-\frac{\varepsilon_k z^2(i+1)}{1+\varepsilon_k\zeta^T(i-1)P(i+1)\zeta(i-1)}<0 \tag{25}$$

4 EXPERIMENT SETUP AND RESULTS

A prototype of the vehicle as shown in Figure 2 with two-wheeled was used to validate the performance of the proposed discrete adaptive controller. The mobile robot utilizes two DC motors equipped with two driving wheels and two caster wheels for supporting the mobile robot's body. A damper is used to ensure the balancing of the mobile robot. In order to determine the mobile robot position, an inertia measurement unit (IMU) is mounted to the center of mass on the robot frame as well as two digital encoders are inserted to two driving wheels. A controller based Arduino 2560 is adopted to implement the command receiving from a computer based controller (CBC) and sending the sensor signal to CBC through Lora wireless communication. A schematic of the control system develops for the mobile robot as shown in Figure 3.

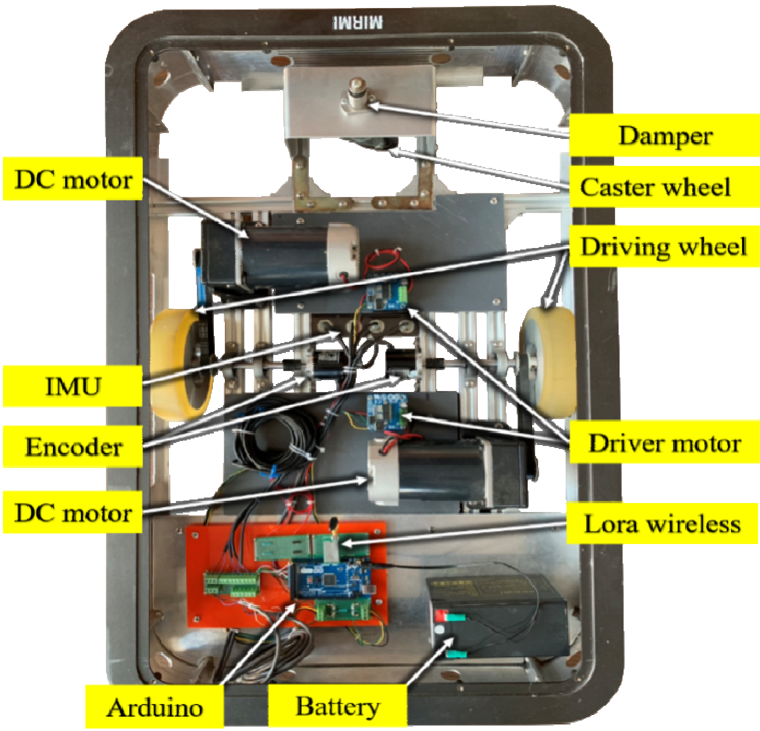

Figure 2: Prototype of Mobile Robot

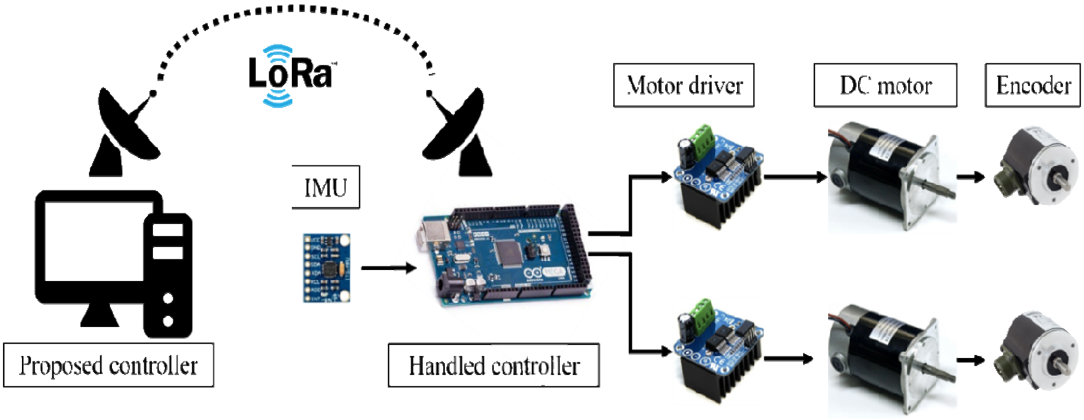

Figure 3: Two-Wheeled Mobile Robot Control Structure

The proposed controller is implemented on CBC with a sampling time 100 milliseconds. The experiment is executed on the prototype of the vehicle, with the initial position of mobile robot as $x(0)=0(m)$, $y(0)=0(m)$ the initial of control input as $u(0)=\begin{bmatrix}0 & 0\end{bmatrix}^T$, and all adjusted adaptive parameters are set to zero.

A desired reference input and the experiment output along to x axis are shown in Figure 4. The desired reference input is denoted in dash line with the amplitude given as $1m$ for the first 5 seconds and that of $0m$ for the last 5 seconds, while the experiment output is denoted in solid line. It is clear to see that the experiment output along to x axis oscillates in the transient phase and tracks the reference input in the steady-state phase.

Figure 5 depicts the experiment output, which compares the desired reference input along to y axis. The desired reference input is denoted in dash line with the amplitude given as $0m$ for the first 2.5 seconds, that of $1m$ for the next 5 seconds, and that of $0m$ for the last 2.5 seconds while the experiment output is denoted in solid line. In the transient phase, the tracking output taken by experiment oscillates then converges to the desired reference input. In the steady state, tracking output closely follows the desired reference input.

The position of the two-wheeled mobile robot in Cartesian frame taken by experiment is shown in Figure 6. It illustrates that the position output of the two-wheeled mobile robot closely tracks the desired reference input in both of the directions along to x axis and y axis.

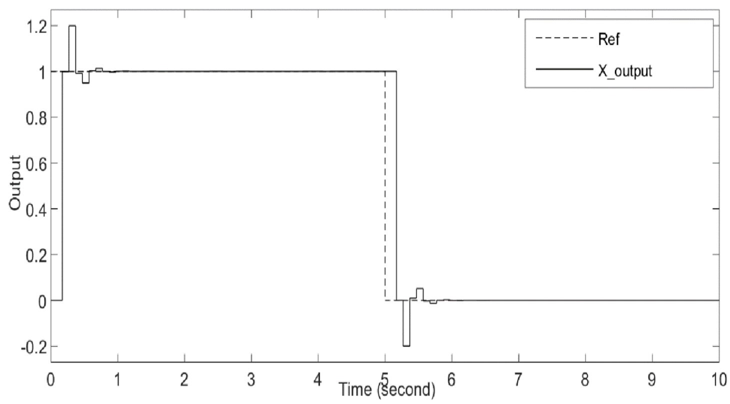

Figure 4: Experiment Output along to X Axis

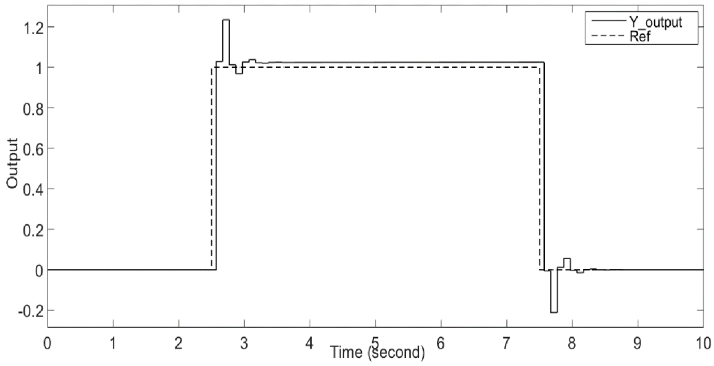

Figure 5: Experiment output along to Y Axis

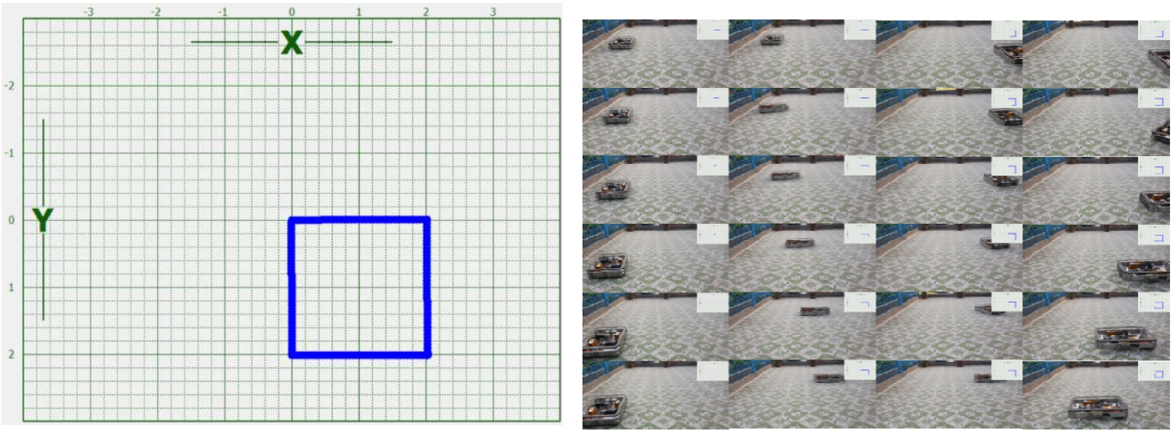

Figure 6: Position in Cartesian Co-ordinate

5 CONCLUSIONS

The remote tracking two-wheeled mobile robot was developed as a real-time industrial application for AGVs robot that can achieve the advantage provided by the Lora wireless communication. However, the typical feature of the wireless network induced delays, which cause to the stability of the control system. As well, a complex structure of mobile robot introduces mismatch modeling and uncertainties that may prevent the good performance tracking of the mobile robot. This paper proposed a discrete-time type of model reference adaptive controller for a remote control system using wireless communication. The adaptive controller and the adaptation control parameters can accommodate the negative effect of the time delay, mismatch modeling and uncertainties of the control plant. Through experiment on a prototype of mobile robot, it is shown that the tracking output of the mobile robot converged to the desired reference input in both cases of study. The paper demonstrated that the proposed controller can improve the tracking ability of the mobile robot in the presence of time delay, mismatch modeling and uncertainties.

For future works, research on the case of the multi of two-wheeled mobile robots, controlled by a remote discrete model reference adaptive controller, is now progress.

REFERENCES

1. *Le, T. A., & De Koster, M. B. M. (2006). A review of design and control of automated guided vehicle systems. European Journal of Operational Research, 171, 1–23*

2. *Ngo, M. D., Vo, H. D., Nguyen, T. P., Kim, S. B., & Oh, M. S. (2007). Two-Wheeled Welding Mobile Robot for Tracking a Smooth Curved Welding Path Using Adaptive Sliding-Mode Control Technique. Int. J. of Control, Automation and Systems, 5, 283–294*
3. *Hossain, K. M., & Sohel, A. A. (2013). Using optical mouse as a position feedback sensor for AGV navigation. Int. J. of Mechanical & Mechatronics Engineering, 13, 33–38*
4. *Ali, M. Y., Hossain, S. G. M., Jamil, H., & Haq, M. Z. (2010). Development of automated guide vehicles for industrial logistics applications in developing countries using appropriate technology. Int. J. of Mechanical & Mechatronics Engineering, 10, 13–18*
5. *Lozoya, C., Matri, P., Velasco, M., & Fuertes, J. M. (2007). Effective real-time wireless control of an autonomous guide vehicle. IEEE International Symposium on Industrial Electronics, Vigo, Spain*
6. *Lian, F. L., Moyne, J. R., & Tilbury, D. M. (2001). Performance evaluation of control networks: Ethernet, Control Net and Device Net. IEEE control systems, 21, 66–83*
7. *Walsh, G. C., Ye, H., & Bushnell, L. G. (2002). Stability Analysis of Networked Control Systems. IEEE Transactions on Control Systems Technology, 10, 438–446*
8. *Wang, C., Wang, Y., & Gao, H. (2004). Compensation time varying delays in networked control system via delay dependent stabilization approach. Proceedings of the 2004 IEEE Int. Conf. on Control Applications, Taipei, Taiwan*
9. *Ofusori, T. J., Ukagu, S. N., Ezomo, P. I., & Guiawa, M. (2014). Mobile Broadband Speed and Data Volume Analysis.*
10. *Halevi, Y., & Ray, A. (1998). Integrated communication and control systems: Part I—Analysis," J. Dynamic Syst., Measure & Control, 110, 367–373*
11. *Nilsson, J. (1998). Real-time control systems with delays. Ph. D. dissertation, Dept. Automatic Control, Lund Institute of Technology, Lund, Sweden*
12. *Yin, C., Gao, J., & Sun, Q. (2014). Enhanced PID Controllers Design Based on Modified Smith Predictor Control for Unstable Process with Time Delay. Mathematical Problems in Engineering, 2014, 1–7*
13. *Kaya, I. (2003). Auto tuning of a new PI-PD smith predictor based on time domain specifications. ISA Transactions, 42, 559–575*
14. *Al Hosni, S. S. (2013). Mobile Learning: Enhancing Learning through Cell Phones (Doctoral dissertation, Doctoral Thesis. Sultan Qaboos University, Oman).*
15. *Carelli, R., Secchi, H., & Mut, V. (1999). Algorithms for Stable Control of Mobile Robots with Obstacle Avoidance. Latin American Applied Research, 29, 191–196*
16. *Kongezos, V. K., & Allen, C. R. (2002). Wireless communication between AGV's (Autonomous Guided Vehicle) and the industrial network CAN (Controller Area Network). Proceedings of the 2002 IEEE International Conference on Robotics and Automation, 1, 434–437*
17. *Duong, V. T., Nguyen, H. H., Jeong, J. H., Kim, H. K., & Kim, S. B. (2018). Back stepping-based mode reference adaptive control for a multi-axial system in the presence of external disturbance and saturated input. Trans. of the Inst. Measurement & Control, 40, 1–9*
18. *Kim, M. S., Shin, J. H., & Lee, J. J. (2000). Design of a robust adaptive controller for a mobile robot. Proceeding of IEEE/RSJ International Conf. on Intelligent Robots and Systems, 1816–1821*
19. *Dong, W., & Guo, Y. (2005). Dynamic tracking control of uncertain mobile robots. IEEE/RSJ International Conf. on Intelligent Robots and Systems, 2774–2779*

20. Dong, W., & Huo, W. (1999). Tracking control of wheeled mobile robots with unknown dynamics. Proceeding of the IEEE International Conf. on Robotics & Automation, Detroit, Michigan

21. Kumar, S., Usmani, T., Saeed, S., & Kidwai, N. A Comparative Analysis Of Advance Three Dimensional Video Coding For Mobile Three Dimensional Tv.

22. Liu, S., Zhang, H., Yang, S. X., & Yu, J. (2004). Dynamic control of a mobile robot using an adaptive neuro-dynamics and sliding mode strategy. Proceeding of the 5th World Congress on Intelligent Control and Automation, Hangzhou, China

23. Zhang, W., Branicky, M. S., & Phillips, S. M. (2001). Stabilize of networked control system. IEEE Control Systems Magazine, 21, 84–99

24. Kokotovic, K. P. V. (1991). Foundations of adaptive control. New York: Springer